



Sedentary Behavior and Health Outcomes in Children and Adolescents

Abstract: *The purpose of this review was to summarize findings from epidemiological studies that determined if sedentary behavior was associated with obesity, metabolic risk factors, and cardiorespiratory fitness in children and adolescents. We noted if studies adjusted for moderate-to-vigorous physical activity (MVPA), dietary intakes, and/or sleep duration. Articles were identified through PubMed using the search terms: (sedentary OR sitting OR television) AND (adiposity OR blood pressure OR body mass index OR cardiometabolic OR metabolic risk OR waist circumference). The search was limited to ages 6 to 18 years, humans, and published between January 1, 2008 and September 26, 2012. Cross-sectional and longitudinal studies observed associations between more sedentary behavior, especially screen-based sedentary behavior, and measures of obesity; and most associations were independent of MVPA and dietary intake. Cross-sectional and longitudinal studies reported associations between screen-based sedentary behavior and lower cardiorespiratory fitness, and most associations were independent of*

MVPA and obesity. Cross-sectional studies observed associations between more screen-based and objectively measured sedentary behavior and lower insulin sensitivity; and most associations were independent of MVPA and obesity. There was little-to-no evidence that sedentary behavior

of waking hours are spent in sedentary behavior.¹ Interestingly, when opportunities to spend time in sedentary behavior were increasing chronic diseases increased in parallel.² These data provide a basis for the hypothesis that spending too much time in sedentary behavior is detrimental to health.

 **Cross-sectional studies cannot determine temporal sequence, but longitudinal studies can provide evidence if sedentary behavior leads to poorer health.** 

was associated with increased blood pressure and increased blood lipids.

Keywords: adolescents; children; metabolic risk; sedentary; television

Introduction

The growth in electronic media, along with the rise in automotive transport, has encouraged sitting and discouraged ambulation, and at present the majority

Epidemiological studies have tested this hypothesis, and indeed there is evidence that excessive sedentary behavior is associated with poorer health.³ However, before drawing conclusions based on such associations, it is important to ask if other health behaviors have been taken into account, notably, physical activity levels and dietary intakes. The rationale for doing so is that an association between sedentary behavior and poor health may be explained by less time

DOI: 10.1177/1559827613498700. Manuscript received January 22, 2013; revised April 21, 2013; accepted May 20, 2013. From Department of Biostatistics and Epidemiology, University of Pennsylvania, Philadelphia, Pennsylvania (JAM) and Clinical Exercise Physiology, Human Performance Laboratory, Ball State University, Muncie, Indiana (WB). Address correspondence to Jonathan A. Mitchell, PhD, Department of Biostatistics and Epidemiology, University of Pennsylvania, 423 Guardian Drive, 222 Blockley Hall, Philadelphia, PA 19104; e-mail: jmitch@mail.med.upenn.edu.

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spent in moderate-to-vigorous physical activity (MVPA) with more time spent in sedentary behavior and/or an increase in caloric intake with more time spent in sedentary behavior.^{4,5} Importantly, not all epidemiological studies have adjusted for these key covariates and so the results of those studies remain open to interpretation. It is also important to consider the study design when assessing evidence of an association between sedentary behavior and health outcomes. Cross-sectional studies cannot determine temporal sequence, but longitudinal studies can provide evidence if sedentary behavior leads to poorer health.

In this review, we will summarize findings from epidemiological studies that investigated the association between sedentary behavior and health outcomes in children and adolescents. The focus on children and adolescents is particularly important as contemporary children and adolescents spend, on average, in excess of 50% of waking hours in sedentary behavior and the proportion of waking hours spent in sedentary behavior increases as children age.⁶⁻⁸ Such high levels of sedentary behavior may be associated with poorer health and in this review we will summarize findings from epidemiological studies that investigated the association between sedentary behavior and obesity, metabolic risk factors, and aerobic fitness.

Methods

Article Search

Key articles were identified through the PubMed database, using the following search terms: (sedentary OR sitting OR television) AND (adiposity OR blood pressure OR body mass index OR cardiometabolic OR metabolic risk OR waist circumference). The search was limited to humans, aged 6 to 18 years, and published in English between January 1, 2008 and September 26, 2012. A total of 907 articles were found, and after reviewing the titles and abstracts 87 articles were identified that investigated

the association between sedentary behavior and health outcomes in youth. Two studies in press were also included in this review, which were not indexed in the PubMed database at the time the search was conducted.^{9,10} Systematic reviews documenting the association between sedentary behavior and health outcomes in children and adolescents have been published.^{11,12} Our review adds to this literature by highlighting and discussing the role of MVPA, dietary intakes, and sleep duration on the relationship between sedentary behavior and health outcomes. We did not include multicomponent lifestyle interventions that included a sedentary behavior component, since our focus was strictly on the health outcomes associated with sedentary behavior.

Sedentary Behavior Definition and Measurement

Sedentary behavior refers to activities that require little-to-no additional energy expenditure above resting metabolic rate (ie, 1.0-1.5 metabolic equivalents).⁴ A recent review by Atkin et al¹³ provides detailed information on the measurement of sedentary behavior in epidemiological studies. Sitting is a common characteristic of sedentary behavior and television viewing is among the most common leisure time sedentary behaviors. Given the latter, self-reported television viewing is frequently used as a measure of sedentary behavior in epidemiological studies. However, studies have also used total time spent in front of electronic screens as a measure of sedentary behavior (eg, sum of time spent watching television, playing video games, and using a computer). Hours per day and hours per week of screen-based sedentary behavior were modeled in some studies^{14,15} whereas other studies categorized participant into specific screen time groups (eg, [≤ 2 or > 2 h/d], [< 1 , 1-3, or 3-6 h/d], [< 2 , 2-4, or > 4 h/d]).¹⁶⁻¹⁸ Other less common self-reported measures of sedentary behavior used in the studies reviewed include reading, talking on the phone, doing homework, and time spent in motorized transport.¹⁹⁻²¹

Accelerometers measure total time spent in sedentary behavior, and this objective approach is advantageous, especially for children, as participants are not required to recall their past behavior. There are protocols in place to determine valid accelerometer data, however, protocols do vary between studies (number of days required [minimum of 3 or 4 days]; wear time per day [minimum of 8 or 10 hours per day]; and consecutive zero counts that constitutes non-wear [10 minutes of consecutive zeros or 60 minutes of consecutive zeros]). All studies included in this review used ActiGraph accelerometer models (AM7164 and GTM1), and most studies used a cutpoint of < 100 counts per minute (cpm) to define sedentary behavior; other cutpoints used were < 200 cpm, < 500 cpm, and < 1100 cpm.²²⁻²⁵ The choice of accelerometer protocol and the sedentary behavior cutpoint used may influence the association with health outcomes in youth.²⁶

Tables

The summary tables in this review are organized by health outcome: obesity (Table 1), blood pressure (Table 2), lipids (Table 3), insulin sensitivity (Table 4), clustered metabolic risk (Table 5), fitness (Table 6), and other health outcomes (Table 7). Within each table, the studies are organized by the name of the first author (A-Z), study year (2008-2012), study design (cross sectional [C.S.], case-control [C-C], longitudinal [L], or randomized controlled trial [RCT]), and by measure of sedentary behavior (self-report or accelerometry). Each table has a column that states if there was an association between sedentary behavior and the health outcome (negative, null, or positive); and each table has columns that state if the association remained after adjusting for MVPA, dietary intake, sleep duration, and when appropriate obesity. If any of these covariates were not included in a study, not applicable (N/A) was used to highlight the absence.

Table 1.
Sedentary Behavior and Obesity in Youth.

Study	Age (Years)	N	Design	Sedentary Behavior	Obesity	Association	Association ^a		
							Adj PA	Adj Diet	Adj Slp
Anderson et al (2008) ¹⁶	4-11	2964	C.S.	TV, video, computer (<2 or ≥2 h/d)	BMI (95th pct)	Null	N/A	N/A	N/A
Eisenmann et al (2008) ³⁵	14-18	12464	C.S.	TV (≤1, 2-3 or ≥4 h/d)	BMI (10TF)	Positive (when PA low)	Modify ^b	N/A	N/A
Laurson et al (2008) ³⁶	7-12	709	C.S.	TV/video/video game (<2 or ≥2 h/d)	BMI (10TF)	Positive (when PA low)	Modify ^b	N/A	N/A
Vicente-Rodriguez et al (2008) ¹⁹	13-18	1960	C.S.	TV/video game/computer/homework/studying (0 = none to 5 = ≥4 h/d)	BMI (10TF)	Positive	+	N/A	N/A
					Skinfolds (85th pct)	Positive	+	N/A	N/A
Wells et al (2008) ¹⁴	10-12	4452	C.S.	TV (<120, 120-239, or ≥240 min/wk)	BMI (10TF)	Positive	+	N/A	+
Xu et al (2008) ⁵⁰	12-18	6848	C.S.	TV (h/wk)	BMI (85th pct)	Positive	+	N/A	+
Aucote et al (2009) ⁵⁹	10-11	393	C.S.	TV (h/wk)	BMI (z score)	Positive (boys)	N/A	N/A	N/A
Fulton et al (2009) ⁵¹	6-15	7802	C.S.	TV and computer (0.0-2.0, 2.5-4.0 or ≥4.5 h/d)	BMI (85th pct)	Positive (girls)	N/A	N/A	N/A
Hume et al (2009) ³⁸	13	580	C.S.	TV and computer (<2, 2-3, 3-4, or >4 h/d)	BMI (10TF)	Null	Null	Null	N/A
					WC (85th pct)	Positive (girls)	+	(girls)	N/A
					Skinfolds (85th pct)	Null	Null	Null	N/A
Lajous et al (2009) ⁶⁰	11-18	9132	C.S.	TV, video, video game (<2, 2-2.9, 3-3.9, 4-4.9, or ≥5 h/d)	BMI (z score)	Positive	+	(boys)	N/A
					Skinfolds (mm)	Positive	+	(boys)	N/A

(continued)

Table 1. (continued)

Study	Age (Years)	N	Design	Sedentary Behavior	Obesity	Association	Association ^a		
							Adj PA	Adj Diet	Adj Slip
Morales-Ruán et al (2009) ⁴⁶	10-19	18 784	C.S.	TV, video games, computer (<7, 7-14, 14-21, or >21 h/wk)	BMI (IOTF)	Positive	+	N/A	N/A
Nogueira et al (2009) ⁶¹	11-15	326	C.S.	TV, video game, computer (h/d)	BMI (kg/m ²)	Null	N/A	N/A	N/A
					Skinfolds (FM/m ²)	Null	N/A	N/A	N/A
Russ et al (2009) ²⁹	6-17	54 863	C.S.	TV, video, video game, computer (h/d)	BMI (95th pctl)	Positive	N/A	N/A	N/A
Steffen et al (2009) ⁶²	8-14	526	C.S.	TV/video/computer	BMI (85th pctl)	Positive	N/A	N/A	N/A
Wong et al (2009) ⁶³	14-17	25 060	C.S.	TV, movies, video game, internet, instant messaging (<1, 1-3, or >3 h/d)	BMI (85th pctl)	Positive (when PA low)	Modify ^b	N/A	N/A
Beyerlein et al (2010) ⁷⁵	5-6	9698	C.S.	TV (<2 or >2 h/d)	BMI (z score)	Positive	N/A	N/A	N/A
Lazarou et al (2010) ¹⁸		622	C.S.	TV, video, DVD (<2, 2-4, or >4 h/d)	BMI (IOTF)	Positive (girls)	N/A	+ (girls)	N/A
Rivera et al (2010) ⁵⁴	7-17	1253	C.S.	TV (<3 vs ≥3 h/d)	BMI (85th pctl)	Null	N/A	N/A	N/A
					Skinfold (85th pctl)	Positive	N/A	N/A	N/A
Sisson et al (2010) ⁶⁸	6-17	53562	C.S.	TV, video, video game (<1, 2-3, or ≥4 h/d)	BMI (85th pctl)	Positive	Modify ^b	N/A	N/A
Thibault et al (2010) ¹⁵	11-18	2385	C.S.	TV, video game, computer (h/wk)	BMI (IOTF)	Positive	+	N/A	N/A
Ulrich-French et al (2010) ⁶²	11-15	153	C.S.	TV, video game, computer (<2 or >2 h/d)	BMI (pctl)	Positive	+	N/A	N/A

(continued)

Table 1. (continued)

Study	Age (Years)	N	Design	Sedentary Behavior	Obesity	Association	Association ^a		
							Adj PA	Adj Diet	Adj Slp
Wen et al (2010) ³⁹	10-12	1362	C.S.	TV, computer (0-7, 7.1-14, or >14 h/wk)	WC (waist:height)	Null	Null	N/A	N/A
Yen et al (2010) ⁶³	15	9278	C.S.	TV (≤2 or >2 h/d)	BMI (IOTF)	Positive	N/A	N/A	N/A
Allender et al (2011) ⁴⁹	14	3040	C.S.	TV, video game, computer (h/d)	BMI (kg/m ²)	Positive	Modify ^b	N/A	N/A
Lehto et al (2011) ⁷⁹	9-11	604	C.S.	TV (h/d)	BMI (WHO)	Null	N/A	N/A	N/A
					WC (cm)	Positive	+	+	+
					WC (waist:height)	Positive	+	+	+
				TV in bedroom (yes or no)	WC (cm)	Positive	+	+	+
					WC (waist:height)	Positive	+	+	+
Mushtaq et al (2011) ¹⁷	5-12	1860	C.S.	TV, video game, computer (<1, 1-3, or 3-6 h/d)	BMI (WHO)	Positive	+	+	N/A
Oliver et al (2011) ⁸⁰	6	102	C.S.	Watch TV everyday (yes or no)	FM (z score)	Positive	N/A	N/A	+
Ozmert et al (2011) ⁶⁴	12-15	860	C.S.	TV—parent report (h/d)	BMI (z score)	Positive	N/A	N/A	N/A
Tovar et al (2012) ⁵⁷	6-11	401	C.S.	TV, video game, computer (≤2 or >2 h/d)	BMI (85th pct)	Null	N/A	N/A	N/A
Tudor-Locke et al (2011) ⁴⁰	5-19	11 658	C.S.	TV—parent reported (h/d)	BMI (IOTF)	Positive	+	N/A	N/A
Peart et al (2011) ³⁰	12-19	2368	C.S.	TV (<2 or ≥2 h/d)	BMI (95th pct)	Positive	+	+	N/A
				Computer (<2 or ≥2 h/d)	BMI (95th pct)	Null	Null	Null	N/A
Perez et al (2011) ³¹	9-16		C.S.	TV, video, computer, video games (≤2 or ≥3 h/d)	BMI (95th pct)	Positive (boys)	Modify ^b	N/A	N/A

(continued)

Table 1. (continued)

Study	Age (Years)	N	Design	Sedentary Behavior	Obesity	Association	Association ^a		
							Adj PA	Adj Diet	Adj Slip
Sisson et al (2011) ⁵⁵	6-17	33 117	C.S.	TV, video game (none, <2, 2-3, or ≥4 h/d)	BMI (85th pct)	Positive	N/A	N/A	N/A
				Computer (none, <2, 2-3, or ≥4 h/d)	BMI (85th pct)	Null	N/A	N/A	N/A
				Reading (none, ≤30, 31-60, or >60 min/d)	BMI (85th pct)	Null	N/A	N/A	N/A
Al-Hazzaa et al (2012) ⁴¹	14-19	2906	C.S.	TV, video game, computer (<2, 2-5, or >5 h/d)	BMI (IOTF)	Null	N/A	N/A	N/A
					WC (waist:height; ≤0.5 or >0.5)	Null	N/A	N/A	N/A
Byun et al (2012) ⁶⁶	12-18	577	C.S.	TV, video game, computer (none, <0.5, 1, 2, 3, 4, 5, 6, or ≥7 h/d)	BMI (≥85th pct)	Positive	+	N/A	N/A
					WC (≥90th pct)	Positive	+	N/A	N/A
Colley et al (2012) ⁶⁵	6-11	878	C.S.	TV, video game, computer—parent report (h/d)	BMI (kg/m ²)	Null	Null	N/A	Null
					WC (cm)	Null	Null	N/A	Null
French et al (2012) ⁶⁶	14	72	C.S.	TV (h/wk)	BMI (z score)	Positive	N/A	N/A	N/A
Lissner et al (2012) ⁴⁷	2-9	15 144	C.S.	TV (<1 or ≥1 h/d)	BMI (IOTF)	Positive	+	+	N/A
				TV in bedroom (yes or no)	BMI (IOTF)	Positive	+	+	N/A
Moraes et al (2012) ⁴⁸	7-9	3636	C.S.	TV and computer (<4 or ≥4 h/d)	BMI (IOTF)	Positive	Null	Null	N/A

(continued)

Table 1. (continued)

Study	Age (Years)	N	Design	Sedentary Behavior	Obesity	Association	Association ^a		
							Adj PA	Adj Diet	Adj Slip
Morley et al (2012) ⁴²	12-17	11 984	C.S.	TV, video, DVD, video game, computer (<4 vs ≥4 h/d)	BMI (OTF)	Positive	+	+	+
Rey-Lopez et al (2012) ⁴³	12-17	2200	C.S.	TV (<2, 2-4 or >4 h/d)	BMI (OTF)	Positive	+	N/A	N/A
					WC (85th pct)	Positive (boys)	+ (boys)	N/A	N/A
					Skinfolds (85th pct)	Positive	+	N/A	N/A
Taylor et al (2012) ⁴⁴	5-15	641	C.S.	TV, video game, computer—parent report (<0.5 vs. ≥2 h/d)	BMI (OTF)	Positive	N/A	N/A	+
Wang et al (2012) ⁴⁵	6-16	4708	C.S.	TV (<1.5 or ≥1.5 h/d)	BMI (OTF)	Positive	+	+	N/A
					WC (90th pct)	Positive	+	+	N/A
Pratt et al (2008) ⁶⁷	12 (girls)	1458	C.S.	Accelerometry (<50 counts/30 s)	BMI (pct)	Positive	N/A	N/A	N/A
					FM (predicted %)	Positive	N/A	N/A	N/A
Mitchell et al (2009) ²²	12	5434	C.S.	Accelerometry (<200 cpm)	FM (< 90th or ≥90th pct, DXA)	Positive	Null	N/A	+
Steele et al (2009) ⁷⁶	9-10	1862	C.S.	Accelerometry (<100 cpm)	BMI (OTF)	Null	Null	N/A	Null
					WC (cm)	Positive	Null	N/A	Null
					FMI (fat mass/m ²)	Positive	Null	N/A	+
McClain et al (2011) ⁸¹	8-11	53	C.S.	Accelerometry (<100 cpm)	FM (% BodyPod)	Null	Null	Null	N/A
Colley et al (2012) ⁶⁵	6-11	878	C.S.	Accelerometry (<100 cpm)	BMI (kg/m ²)	Null	N/A	N/A	N/A

(continued)

Table 1. (continued)

Study	Age (Years)	N	Design	Sedentary Behavior	Obesity	Association	Association ^a		
							Adj PA	Adj Diet	Adj Sp
Chaput et al (2012) ⁷⁷	8-10	550	C.S.	Accelerometry (<100 cpm)	WC (cm)	Null	N/A	N/A	N/A
Ekelund et al (2012) ⁷⁸	4-18	20 871	C.S.	Accelerometry (<100 cpm)	FM (% DXA)	Null	Null	Null	Null
Cecil-Karb et al (2009) ⁶⁸	12-20	5886	L	TV (h/weekday)	WC (waist:height)	Null	Null	Null	Null
Barnett et al (2010) ⁶⁹	13-17	1192	L	TV, video, computer ("steady-low," "steady-high," "increasers," and "decreasers")	WC (cm)	Null	Null	N/A	N/A
Danner et al (2008) ³²	5-11	7334	L	TV/video/DVD—parent report (h/d)	BMI (kg/m ²)	Positive	N/A	N/A	N/A
Fulton et al (2009) ⁷⁰	8-14	472	L	TV, reading, computer	BMI (kg/m ²)	Positive for increasers (boys)	Modify ^b (boys)	+	N/A
Hands et al (2011) ⁷¹	6-14	1403	L	TV, video game, computer (<2 or >2 h/d)	BMI (kg/m ²)	Positive	+	N/A	N/A
Altenburg et al (2012) ⁷²	13-14	465	L	TV, computer (min/d)	BMI (kg/m ²)	Positive (boys)	N/A	N/A	N/A
					Skinfolds (mm)	Positive	N/A	N/A	N/A
					WC (cm)	Null	N/A	N/A	N/A
					HC (cm)	Null	N/A	N/A	N/A

(continued)

Table 1. (continued)

Study	Age (Years)	N	Design	Sedentary Behavior	Obesity	Association	Association ^a		
							Adj PA	Adj Diet	Adj Slp
Mitchell et al (2012) ⁹	9-19	1702	L	Television (h/wk)	Skinfolds (mm)	Positive	+	+	+
Mitchell et al (2012) ¹⁰	14-18	1336	L	TV, computer (h/d)	BMI (kg/m ²)	Positive	+	N/A	+
Treuth et al (2009) ³³	12-14	984	L	Accelerometry (<50 counts/30 s)	BMI (95th pctl)	Null	N/A	N/A	N/A
					FM (≥35%)	Null	N/A	N/A	N/A
Fisher et al (2011) ⁷³	8-10	280	L	Accelerometry (<100 cpm)	BMI (kg/m ²)	Null	Null	N/A	N/A
					FMI (FM/m ²)	Null	Null	N/A	N/A
					WC (cm)	Null	Null	N/A	N/A
Basterfield et al (2012) ²⁴	7-9	403	L	Accelerometry (<1100 cpm)	BMI (z-score)	Null	N/A	N/A	N/A
					FMI (FM/m ²)	Positive	Null	N/A	N/A
Mitchell et al (2012) ²²	9-15	789	L	Accelerometry (<100 cpm)	BMI (kg/m ²)	Positive	+	+	+
Epstein et al (2008) ¹⁰⁸	4-7	70	RCT	Intervention: 50% reduction in TV	BMI (z-score)	Intervention lowered BMI z score vs control			

Abbreviations: Adj, adjusted; BMI, body mass index; C.S., cross-sectional; cpm, counts per minute; DXA, dual-energy X-ray absorptiometry; FM, fat mass; HC, hip circumference; IOTF, International Obesity Task Force; L, longitudinal; N/A, not applicable; PA, physical activity; pct, percentile; RCT, randomized controlled trial; Slp, sleep; TV, television; WC, waist circumference; WHO, World Health Organization.

^aAssociation between sedentary behavior and measures of obesity after adjusting for physical activity, dietary intake, sleep, and obesity.

^bModify, interaction between moderate-to-vigorous physical activity and sedentary behavior.

Table 2.
Sedentary Behavior and Blood Pressure in Youth.

Study	Age (Years)	N	Design	Sedentary	Blood Pressure	Association	Association ^a			
							Adj PA	Adj Diet	Adj Slp	Adj Ob
Lazarou et al (2009) ⁸³	10-13	622	C.S.	TV (≤ 2 vs > 2 h/d)	SBP (≥ 90 th pctl)	Null	Null	N/A	Null	
Martinez-Gomez et al (2009) ⁸⁴	3-8	111	C.S.	TV and computer—parent reported (h/d)	DBP (≥ 90 th pctl)	Null	Null	N/A	Null	
Ulrich-French et al (2010) ⁸²	11-15	153	C.S.	TV, video game, computer (≤ 2 or > 2 h/d)	SBP (mm Hg)	Positive	N/A	N/A	N/A	
Hardy et al (2010) ²¹	15	496	C.S.	TV, DVD, video, computer (< 2 or ≥ 2 h/d)	DBP (mm Hg)	Null	Null	N/A	N/A	
Goldfield et al (2011) ⁸⁵	14-18	282	C.S.	TV, video game, computer	SBP (≥ 90 th pctl)	Null	N/A	N/A	N/A	
Byun et al (2012) ⁸⁶	12-18	577	C.S.	TV, video game, computer (h/d)	DBP (≥ 90 th pctl)	+ (Boys)	Null	N/A	Null	
Gopinath et al (2012) ⁸²	12	2353	C.S.	TV (< 1 , 1-2, or ≥ 2 h/d)	SBP, DBP	Null	Null	N/A	Null	
					SBP, DBP (≥ 90 th pctl)	Null	Null	N/A	N/A	
					SBP (mm Hg)	Positive	Null	N/A	Null	

(continued)

Table 2. (continued)

Study	Age (Years)	N	Design	Sedentary	Blood Pressure	Association	Association ^a			
							Adj PA	Adj Diet	Adj Slp	Adj Ob
					DBP (mmHg)	Positive	N/A	N/A	N/A	+
					MABP (mm Hg)	Positive	N/A	N/A	N/A	+
				Reading (<1, 1-2, or ≥2 h/d)	SBP (mm Hg)	Negative	N/A	N/A	N/A	-
					DBP (mm Hg)	Negative	N/A	N/A	N/A	-
					MABP (mm Hg)	Negative	N/A	N/A	N/A	-
Gava et al (2009) ²⁵	8-17	2184	C.S.	Accelerometry (<500 cpm)	SBP (mm Hg)	Positive	N/A	N/A	N/A	+
Martinez-Gomez et al (2009) ⁶⁴	3-8	111	C.S.	Accelerometry (<50 counts/30 s)	SBP (mm Hg)	Null	N/A	N/A	N/A	Null
					DBP (mm Hg)	Null	N/A	N/A	N/A	Null
Ekelund et al (2012) ⁷⁸	4-18	20 871	C.S.	Accelerometry (<100 cpm)	SBP (mm Hg)	Null	N/A	N/A	N/A	N/A
Mitchell et al (2012) ⁹	9-19	1702	L	TV (h/wk)	SBP (mm Hg)	Null	Null	Null	Null	N/A

Abbreviations: Adj, adjusted; C.S., cross-sectional; cpm, counts per minute; DBP, diastolic blood pressure; L, longitudinal; N/A, not applicable; PA, physical activity; Ob, obesity; pcti, percentile; SBP, systolic blood pressure; Slp, sleep; TV, television.

^aAssociation between sedentary behavior and blood pressure after adjusting for physical activity, dietary intake, sleep, and obesity.

Table 3.
Sedentary Behavior and Lipids in Youth.

Study	Age (Years)	N	Design	Sedentary	Lipid	Association	Association ^a			
							Adj PA	Adj Diet	Adj Sip	Adj Ob
Hardy et al (2010) ²¹	15	496	C.S.	TV, DVD, video, computer (<2 or ≥2 h/d)	HDL-C (<40 mg/dL)	Null	N/A	N/A	N/A	N/A
					LDL-C (>130 mg/dL)	Null	N/A	N/A	N/A	N/A
					TG (>199 mg/dL)	Null	N/A	N/A	N/A	N/A
Goldfield et al (2011) ⁹⁵	14-18	282	C.S.	TV, video game, computer	TC	Null	Null	N/A	Null	Null
					HDL-C	Null	Null	N/A	Null	Null
					LDL-C	Null	Null	N/A	Null	Null
					TG	Null	Null	N/A	Null	Null
Byun et al (2012) ⁹⁶	12-18	577	C.S.	TV, video game, computer (h/d)	LDL-C (≥130 mg/dL)	Null	Null	N/A	Null	N/A
					HDL-C (≤35 mg/dL)	Positive	+	N/A	N/A	N/A
					TG (≥130 mg/dL)	Null	Null	N/A	Null	N/A
Ekelund et al (2012) ⁷⁸	4-18	20 871	C.S.	Accelerometry (<100 cpm)	TG (mg/dL)	Null	Null	N/A	Null	N/A
					HDL-C (mg/dL)	Null	Null	N/A	Null	N/A
Mitchell et al (2012) ⁹	9-19	1702	L	TV (h/wk)	TG (mg/dL)	Null	Null	Null	Null	N/A
					LDL-C (mg/dL)	Null	Null	Null	Null	N/A
					HDL-C (mg/dL)	Null	Null	Null	Null	N/A
					TC:HDL-C (mg/dL)	Null	Null	Null	Null	N/A

Abbreviations: Adj, adjusted; C.S., cross-sectional; cpm, counts per minute; HDL-C, high-density lipoprotein cholesterol; L, longitudinal; LDL-C, low-density lipoprotein cholesterol; N/A, not applicable; Ob, obesity; PA, physical activity; Sip, sleep; TV, television.

^aAssociation between sedentary behavior and blood lipids after adjusting for physical activity, dietary intake, sleep, and obesity.

Table 4.
Sedentary Behavior and Insulin Sensitivity in Youth.

Study	Age (Years)	N	Design	Sedentary	Insulin Sensitivity	Association	Association ^a			
							Adj PA	Adj Diet	Adj Slp	Adj Ob
Hardy et al (2010) ²¹	15	496	C.S.	TV, DVD, video, computer (<2 or ≥2 h/d)	Insulin (≥75 th pctl)	Positive (boys)	+	+	N/A	+
					Glucose (≥75 th pctl)	Null	N/A	N/A	N/A	N/A
					HOMA-IR	Positive (boys)	+	+	N/A	+
Henderson et al (2012) ⁸⁷	8-10	420	C.S.	TV, video game, computer (h/d)	Insulin	Positive	+	+	N/A	Null
					HOMA-IR	Positive	+	+	N/A	Null
					Matsuda Index	Negative	-	-	N/A	Null
Sardinha et al (2008) ²³	10	308	C.S.	Accelerometry (<500 cpm)	HOMA-IR	Positive	+	+	N/A	+
Ekelund et al (2012) ⁷⁶	4-18	20 871	C.S.	Accelerometry (<100 cpm)	Insulin (pmol/L)	Positive	Null	Null	N/A	N/A
Henderson et al (2012) ⁸⁷	8-10	420	C.S.	Accelerometry (<100 cpm)	Insulin (pmol/L)	Positive	+	+	N/A	Null
					HOMA-IR	Positive	+	+	N/A	+
					Matsuda Index	Negative	Null	Null	N/A	Null
Lobelo et al (2010) ⁸⁸	10-20	384	C-C	TV, video, video games, internet (h/d)	T2DM (cases)	Null	N/A	N/A	N/A	Null

Abbreviations: Adj, adjusted; C.S., cross-sectional; cpm, counts per minute; HOMA-IR, Homeostatic Model Assessment for Insulin Resistance; N/A, not applicable; Ob, obesity, PA, physical activity; Slp, sleep; TV, television.

^aAssociation between sedentary behavior and insulin sensitivity after adjusting for physical activity, dietary intake, sleep, and obesity.

Table 5. Sedentary Behavior and Clustered Metabolic Risk in Youth.

Study	Age (Years)	N	Design	Sedentary	Metabolic Risk	Association	Association ^a				
							Adj PA	Adj Diet	Adj Slp	Adj Ob	
Mark et al (2008) ⁸⁸	12-19	1803	C.S.	TV, video, and computer ($\leq 1, 2, 3, 4,$ and ≥ 5 h/d)	Metabolic syndrome (≥ 3 :high TG, glucose, WC, BP, or low HDL-C; age-specific pct)	Positive	+	N/A	N/A	N/A	N/A
Kang et al (2010) ⁸⁹	10-18	845	C.S.	TV and computer (h/wk quartiles)	Metabolic syndrome (≥ 3 :high WC, BP, glucose, TG, or low HDL-C)	Positive	N/A	N/A	N/A	N/A	N/A
Martinez-Gomez et al (2010) ⁹¹	13-18	425	C.S.	TV (≤ 3 vs > 3 h/d)	Risk Scr (z-score: Glucose, HDL-C, LDL-C, and TG)	Positive	N/A	N/A	N/A	N/A	+
Carson et al (2011) ⁹³	6-19	2527	C.S.	TV ($< 1, 1, 2-3, \geq 4$ h/d)	Risk Scr (Quartiles: WC, BP, HDL-C, Non-HDL-C, C-reactive protein)	Positive	+	+	N/A	N/A	N/A
Hsu et al (2012) ²⁰	10-16	105	C.S.	TV, video games, Internet, talking on the phone (h/d)	Metabolic syndrome (≥ 3 :high WC, TG, BP, glucose, or low HDL-C)	Positive	+	N/A	N/A	N/A	+
Chinapaw et al (2012) ⁹²	12	142	C.S.	TV and computer (min/d)	Risk Scr (sum z-scores: WC, glucose, LDL-C, HDL-C, TG, and C-peptide)	Null	Null	N/A	N/A	N/A	N/A
Rey-Lopez et al (2012) ⁹⁴	12-17	769	C.S.	TV (min/d)	Risk Scr (sum z-scores: HOMA, TG, TC:HDL-C, VO2max, & skinfolds)	Null	Null	N/A	N/A	N/A	N/A
				Video games (min/d)	Risk Scr (sum z-scores: HOMA, TG, TC:HDL-C, VO2max, & skinfolds)	Positive (boys)	+	N/A	N/A	N/A	N/A

(continued)

Table 5. (continued)

Study	Age (Years)	N	Design	Sedentary	Metabolic Risk	Association	Association ^a			
							Adj PA	Adj Diet	Adj Slip	Adj Ob
Martinez-Gomez et al (2010) ⁹⁰	13-17	210	C.S.	Accelerometry (<100 cpm, tertiles)	Risk Scr (z score: BP, glucose, HDL-C, and TG)	Positive	N/A	N/A	N/A	N/A
Carson et al (2011) ⁹³	6-19	2527	C.S.	Accelerometry (<100 cpm)	Risk Scr (Quartiles: WC, BP, HDL-C, Non-HDL-C, C-reactive protein)	Null	Null	N/A	N/A	N/A
Chinapaw et al (2012) ⁹²	12	142	C.S.	Accelerometry (<100 cpm)	Risk Scr (sum z scores: WC, Gluc, LDL-C, HDL-C, TG & C-peptide)	Null	Null	N/A	N/A	N/A
Hsu et al (2012) ²⁰	10-16	105	C.S.	Accelerometry (<100 cpm)	Metabolic syndrome (≥ 3 :high WC, TG, BP, glucose, or low HDL-C)	Null	Null	N/A	N/A	Null
Mitchell et al (2012) ⁹	9-19	1702	L	Television (h/wk)	Risk Scr (sum z scores: skinfolds, TG, SBP, LDL-C, TC:HDL-C)	Null	Null	Null	Null	N/A

Abbreviations: Adj, adjusted; BP, blood pressure; C.S., cross-sectional; cpm, counts per minute; HDL, high-density lipoprotein cholesterol; L, longitudinal; LDL-C, low-density lipoprotein cholesterol; N/A, not applicable; Ob, obesity; PA, physical activity; pct, percentile; SBP, systolic blood pressure; Slip, sleep; TC, total cholesterol; TG, triglycerides; TV, television; WC, waist circumference.

^aAssociation between sedentary behavior and clustered metabolic risk after adjusting for physical activity, dietary intake, sleep, and obesity.

Table 6.
Sedentary behavior and fitness in youth.

Study	Age (Years)	N	Design	Sedentary	Fitness	Association	Association ^a			
							Adj PA	Adj Diet	Adj Slp	Adj Ob
Hardy et al (2009) ⁹⁷	11-15	2750	C.S.	TV, video games, computer (h/d)	20-m shuttle run (laps)	Negative	-	N/A	N/A	-
				TV, video games, computer, homework, motorized travel, reading, hobbies, musical instrument, listening to music, sitting talking (h/d)	20-m shuttle run (laps)	Negative (girls)	– (girls)	N/A	N/A	– (girls)
Lobelo et al (2009) ¹⁰²	13-17	5210	C.S.	TV, video, video game, and internet use (<2 and ≥2 h/d)	PWC ₁₇₀	Negative	N/A	N/A	N/A	-
Mota et al (2010) ¹⁰⁰	7	135	C.S.	TV (<2 or >2 h/d)	9-min run/walk (meters)	Negative	N/A	N/A	N/A	N/A
Aires et al (2011) ¹⁰¹	11-19	1708	C.S.	TV (h/d)	20-m shuttle run (laps)	Negative	-	N/A	N/A	-
Martinez-Gomez et al (2011) ¹⁰⁹	12-17	1808	C.S.	Accelerometry (<100 cpm)	20-m shuttle run (girls: ≤35/≤38 mL/kg/min; boys: ≤42 mL/kg/min)	Negative	Modify ^b	N/A	N/A	-
Aggio et al (2012) ⁹⁸	11	1500	C.S.	TV (<2 or 2 h/d)	20-m shuttle run (girls: ≤35; boys: ≤40 mL/kg/min)	Negative	N/A	N/A	N/A	-
Sandercoc et al (2012) ⁹⁹	10-16	6819	C.S.	TV, video game, computer (<2, 2-4, or >4 h/d)	20-m shuttle run (girls: ≤35; boys: ≤40 mL/kg/min)	Negative	-	N/A	N/A	-

(continued)

Table 6. (continued)

Study	Age (Years)	N	Design	Sedentary	Fitness	Association	Association ^a			
							Adj PA	Adj Diet	Adj Slp	Adj Ob
Lobelo et al (2009) ¹⁰²	13-17	320	L	TV, video, video game, and Internet use (<2 and ≥2 h/d)	PWC ₁₇₀	Negative	N/A	N/A	N/A	–
Aires et al (2010) ¹⁰³	11-19	185	L	TV, computer (hours on previous day)	Fitness z score: sum of 20 m shuttle run (z score), curl-up (z score), and push-up (z score)	Null	Null	N/A	N/A	Null
Mota et al (2010) ¹⁰⁰	7-9	135	L	TV (<2 or >2 h/d)	9-min run/walk (meters)	Negative	N/A	N/A	N/A	N/A
Aggio et al (2012) ⁹⁸	11-13	1500	L	TV (<2 or 2 h/d)	20-m shuttle run (girls: ≤35 or >35 mL/kg/min and boys: ≤40 or >40 mL/kg/min)	Null	N/A	N/A	N/A	Null
Mitchell et al (2012) ⁹⁶	11-13	2097	L	TV, video game, computer (h/d)	20-m shuttle run (laps)	Negative	–	N/A	N/A	–

Abbreviations: Adj, adjusted; C.S., cross-sectional; cpm, counts per minute; L, longitudinal; N/A, not applicable; Ob, obesity; PA, physical activity; PWC₁₇₀, power at work capacity to elicit a heart rate of 170 beats per minute; Slp, sleep; TV, television.

^aAssociation between sedentary behavior and fitness after adjusting for physical activity, dietary intake, sleep, and obesity.

^bModify, interaction between moderate-to-vigorous physical activity and sedentary behavior.

Table 7.
Sedentary Behavior and Health Outcomes in Youth.

Study	Age (Years)	N	Design	Sedentary	Health Outcome	Association	Association ^a			
							Adj PA	Adj Diet	Adj Slip	Adj Ob
Hardy et al (2010) ²¹	15	496	C.S.	TV, DVD, video, computer (<2 or ≥2 h/d)	ALT (>30 U/L)	Null	N/A	N/A	N/A	N/A
					hs-CRP (>10 mg/dL)	Positive (boys)	Null	Null	N/A	Null
					GGT (>30 U/L)	Null	N/A	N/A	N/A	N/A
Gopinath et al (2011) ¹⁰⁵	6	1765	C.S.	TV, video game, computer (h/d)	Retinal arteriolar caliber (µm)	Negative	N/A	N/A	N/A	-
Martinez-Gomez et al (2012) ¹⁰⁴	13-17	183	C.S.	Accelerometry (<100 cpm)	WBC, CRP, IL-6, C3, C4, adiponectin, leptin, ICAM-1, VCAM-1, L-selectin, E-selectin, and PAI-1	Null	Null	N/A	N/A	Null
				TV (h/d)	WBC, CRP, IL-6, C3, C4, adiponectin, leptin, ICAM-1, VCAM-1, L-selectin, E-selectin, and PAI-1	Null	Null	N/A	N/A	Null
Nettleford et al (2012) ¹⁰⁶	10	105	C.S.	Accelerometry (<1.5 METs)	Large artery compliance (mL/mm Hg × 100)	Null	N/A	N/A	N/A	N/A
					Small artery compliance (mL/mm Hg × 100)	Null	N/A	N/A	N/A	N/A
Xi et al (2011) ¹⁰⁷	6-18	2848	C-C	Gene-environment interaction: (TV, video game, computer [<2 or ≥2 h/d]) * (genetic risk score)	Obesity (cases)	Positive (high genetic risk score)	Modify	N/A	N/A	N/A

Abbreviations: Adj, adjusted; ALT, alanine aminotransferase; C3, complement factor 3; C4, complement factor 4; C.S., cross-sectional; cpm, counts per minute; CRP, C-reactive protein; GGT, γ-glutamyltransferase; ICAM-1, intercellular adhesion molecule 1; IL-6, interleukin-6; MET, metabolic equivalent; N/A, not applicable; Ob, obesity; PA, physical activity; PAI-1, plasminogen activator inhibitor-1; Slip, sleep; TV, television; VCAM-1, vascular cell adhesion molecule 1; WBC, white blood cell.

^aAssociation between sedentary behavior and health outcome after adjusting for physical activity, dietary intake, sleep, and obesity.

Obesity Outcomes

The prevalence of childhood obesity in the United States is 17%.²⁷ This estimate is based on the proportion of youth with a body mass index (BMI) \geq 95th Centers for Disease Control and Prevention growth chart percentile,²⁸ and a number of studies included in this review used this cutoff to define obesity.^{16,29-33}

However, most studies included used the International Obesity Task Force cutoff³⁴ to define obesity,^{15,18,19,35-48} and 2 studies used the World Health Organization reference data to define obesity.^{17,49} Some studies did not specifically define obesity based on BMI, but defined overweight using Centers for Disease Control and Prevention growth chart data (\geq 85th BMI percentile).⁵⁰⁻⁵⁸ Electing not to categorize participants into BMI groups, several studies modeled the mean BMI (raw BMI, BMI *z* score, or BMI percentile),^{24,59-73} or the median BMI and other percentiles of the BMI distribution.^{10,74,75}

Several studies included in this review measured waist circumference to provide an estimate of abdominal fat mass*; some measured skinfold thickness to provide an estimate of subcutaneous fat mass, or converted skinfold thickness into percent body fat using prediction equations.^{9,19,38,43,54,60,72} Fat mass was also measured using bioelectrical impedance, densitometry, and dual energy X-ray absorptiometry.^{22,24,33,67,73,76,77,80,81}

Blood Pressure Outcomes

Automated^{25,78,82} and mercury sphygmomanometers⁸³⁻⁸⁵ were used to measure diastolic blood pressure (DBP), mean arterial blood pressure (MABP), and systolic blood pressure (SBP) in studies included in this review. Blood pressure measurements were taken after a period of rest that ranged from 4 minutes⁸⁵ to 15 minutes.⁸³ All blood pressures were expressed in millimeters of mercury (mm Hg). The mean, or median, mm Hg was modeled for each blood pressure measure, except in 3 studies that categorized participants into high and low DBP and SBP groups.^{21,56,83}

*References 38, 41, 43, 45, 56, 62, 65, 72, 73, 76-79.

Lipid Outcomes

Enzymatic methods (high-density lipoprotein cholesterol [HDL-C], total cholesterol [TC], and triglycerides [TG]) and the Friedwald equation (low-density lipoprotein cholesterol [LDL-C]) were used to measure lipid levels in fasting blood in studies included in this review.^{9,21,56,78,85}

Each lipid was expressed in milligrams per deciliter (mg/dL); and the mean, or median, mg/dL was modeled in each study, except in 2 studies that categorized participants in high and low groups (HDL-C, \leq 35 mg/dL or $>$ 35 mg/dL; LDL-C, \leq 130 mg/dL or $>$ 130 mg/dL; TG, \leq 130 mg/dL or $>$ 130 mg/dL).^{21,56}

Insulin Sensitivity

Insulin sensitivity refers to the degree to which the body responds to circulating insulin. Type 2 diabetics are insulin resistant and one study determined if sedentary behavior differed between type 2 diabetic cases and healthy controls.⁸⁶ Three studies estimated insulin sensitivity using the Homeostasis Model for Assessment for Insulin Resistance (HOMA-IR) calculation (HOMA-IR = [fasting glucose \times fasting insulin]/22.5).^{21,23,87} One study performed oral glucose tolerance tests (OGTT), where participants received an oral glucose load (1.75 g/kg), after an overnight fast, and blood was sampled at 30, 60, 90, and 120 minutes after the glucose administration.⁸⁷ The Matsuda Index was then calculated to provide a measure of insulin sensitivity (Matsuda Index = $10000/\sqrt{[(\text{fasting glucose} \times \text{fasting insulin}) \times (\text{mean OGTT glucose} \times \text{mean OGTT insulin})]}$).⁸⁷

Clustered Metabolic Risk

Metabolic syndrome and clustered metabolic risk scores provide an estimate of overall metabolic risk, and 3 studies included in this review investigated metabolic syndrome,^{20,88,89} and 6 studies investigated clustered metabolic risk scores.^{9,90-94} For metabolic syndrome, participants were categorized as having metabolic syndrome if at least 3 metabolic risk factors were defined as being high.^{20,88,89} In those studies, different metabolic risk factors were

considered in the definition; and different cutoffs to define high levels of the individual metabolic risk factors were used across studies.^{20,88,89} For clustered metabolic risk scores, participants are not categorized as having, or not having, metabolic syndrome. Rather, *z* scores are calculated for the individual metabolic risk factors and the metabolic risk score is the sum of those *z* scores.^{9,90-94} However, not all studies included in this review used the same individual metabolic risk factors to calculate clustered metabolic risk scores.

Fitness Outcomes

Submaximal field tests have been established that allow for the measurement of cardiorespiratory fitness (CRF) in epidemiological studies.⁹⁵ Five studies included in this review estimated CRF using the 20-m shuttle run field test, where participants completed 20-m laps at an initial pace of 8.5 km/h, with the pace increasing by 0.5 km/h every minute thereafter, and the more laps completed indicates higher CRF.⁹⁶⁻¹⁰¹ Using stationary cycles, one study determined the power needed to elicit a heart rate of 170 beats per minute (power at work capacity to elicit a heart rate of 170 beat per minute, PWC₁₇₀). Greater power needed to achieve a heart rate of 170 beats per minute indicates higher CRF.¹⁰² The 9-minute walk/run test was used in one study to estimate CRF; the more meters covered over 9 minutes indicates higher CRF.¹⁰⁰ One study measured both CRF (20-m shuttle run) and muscular strength (number of push-ups and curl-ups), and created an overall fitness *z* score.¹⁰³

Other Health Outcomes

The associations between sedentary behavior and adipokines,¹⁰⁴ markers of inflammation,¹⁰⁴ markers of nonalcoholic fatty liver disease,²¹ retinal vasculature health,¹⁰⁵ and arterial stiffness¹⁰⁶ were investigated in studies included in this review. These health outcomes have not been extensively studied, at this time, and so are listed together under "other health outcomes" for the purpose of this review. One study determined if there was an

interaction between obesity susceptibility loci and sedentary behavior with regard to obesity,¹⁰⁷ and this study was also listed under “other health outcomes.”

Results

Sedentary and Obesity (Table 1)

Forty-three cross-sectional studies investigated the association between self-reported sedentary behavior and measures of obesity. Null associations were reported between screen-based sedentary behavior and BMI in 10 studies;[†] skinfolds in 2 studies;^{38,61} and waist circumference (WC) in 3 studies.^{41,62,65} Screen-based sedentary behavior was associated with higher BMI in 33 studies,[‡] thicker skinfolds in 4 studies,^{19,43,54,60} larger WC in 5 studies,^{38,43,45,56,79} and higher fat mass in 1 study.⁸⁰ Of the 33 studies that found an association between sedentary behavior and higher BMI, 16 adjusted for MVPA, and the associations remained in 15 of those studies.[§] Of the 4 studies that found an association between sedentary behavior and thicker skinfolds, 3 adjusted for MVPA and the associations remained in all 3 studies.^{19,43,60} Of the 5 studies that found an association between sedentary behavior and larger WC, 4 adjusted for MVPA and the associations remained in all 4 of those studies.^{43,45,56,79} Six studies tested if MVPA modified the association between screen-based sedentary behavior and increased BMI.^{31,35,36,53,63} In those studies, screen-based sedentary behavior was associated with increased BMI only when MVPA was low.^{31,35,36,53,58,63} In the studies that also adjusted for dietary intakes and/or sleep duration, the cross-sectional associations between screen-based sedentary behavior and BMI and WC remained.^{14,18,42,44-47,50,60}

[†]References 16, 30, 38, 41, 49, 54, 55, 57, 61, 65.

[‡]References 14, 15, 17-19, 29-31, 35, 36, 39, 40, 42-48, 50-53, 55, 56, 58-60, 62-64, 66, 75.

[§]References 14, 15, 17, 19, 30, 40, 42, 43, 45-47, 50, 56, 60, 62.

Seven cross-sectional studies investigated the association between objectively measured sedentary behavior and measures of obesity.^{22,65,67,76-78,81} Null associations were reported between objectively measured sedentary behavior and BMI in 2 studies;^{65,76} WC in 3 studies;^{65,77,78} and fat mass in 2 studies.^{78,81} Objectively measured sedentary behavior was associated with higher BMI in 1 study,⁶⁷ larger WC in 1 study,⁷⁶ and higher fat mass in 3 studies.^{22,67,76} Interestingly, the positive associations between objectively measured sedentary behavior and the measures of obesity became null in the 2 studies that adjusted for MVPA.^{22,76} The cross-sectional associations between objectively measured sedentary behavior and measures of obesity remained in those studies that adjusted for dietary intake and/or sleep duration.^{22,76,77,81}

Eight longitudinal studies investigated the association between screen-based sedentary behavior and measures of obesity over time.^{9,10,32,68-72} Null associations between screen-based sedentary behavior and changes in WC, and changes in hip circumference, were reported by Altenberg et al.⁷² Screen-based sedentary behavior was associated with greater increases in BMI over time in 6 studies,^{10,32,68-72} and greater increases in skinfold thickness over time in 2 studies.^{9,72} Those positive associations remained in 4 longitudinal studies that adjusted for MVPA;^{9,10,70,71} and those positive associations also remained in 3 longitudinal studies that adjusting for dietary intake and/or sleep duration.^{9,10,70}

Four longitudinal studies investigated the association between objectively measured sedentary behavior and measures of obesity.^{24,33,73,74} Null associations were reported between objectively measured sedentary behavior and change in BMI in three studies;^{24,33,73} whereas Mitchell et al⁷⁴ reported an association between more objectively measured sedentary behavior and greater increases in BMI from age 9 to 15 years. The positive association in the latter study remained after adjusting for MVPA, dietary intake and sleep duration.⁷⁴ Fisher et al⁷³ reported null associations

between objectively measured sedentary behavior and changes in fat mass and waist circumference over time; and Treuth et al³³ reported a null association between objectively measured sedentary behavior and change in percentage fat mass over time. Interestingly, Basterfield et al²⁴ reported a positive association between objectively measured sedentary behavior and fat mass over time, but that association became null after adjusting for MVPA.

One randomized controlled trial delivered a television reduction intervention, and found that those assigned to the intervention arm had lower BMI *z* scores compared to the control group at 6 months and 24 months after the start of the intervention.¹⁰⁸ Interestingly, the reduction in television viewing in the intervention group coincided with a reduction in caloric intake.¹⁰⁸

Sedentary Behavior and Blood Pressure (Table 2)

Eight cross-sectional studies investigated the association between screen-based sedentary behavior and blood pressure in youth.^{21,25,56,62,82-85} Null associations were reported between screen-based sedentary behavior and DBP in 6 studies^{21,56,62,83-85} and SBP in 4 studies.^{21,56,83,85} Three studies observed that more screen-based sedentary behavior was associated with increased SBP,^{62,82,84} and the association remained in one of those studies after adjusting for MVPA.⁶² Gopinath et al⁸² observed that more screen-based sedentary behavior was associated with higher DBP, and MABP, and those associations remained after adjusting for MVPA and obesity. Interestingly, Gopinath et al⁸² also measured time spent reading and observed that more reading was associated with lower SBP, DBP, and MABP; and these associations remained after adjusting for MVPA and obesity.

Ekelund et al⁷⁸ objectively measured sedentary behavior and observed a null association between sedentary behavior and SBP. In contrast, Gaya et al²⁵ observed an increase in SBP with more objectively measured sedentary behavior,

and the association remained after adjusting for BMI. Mitchell et al⁹ investigated the longitudinal association between television viewing and changes in SBP over time, and observed a null association.

Sedentary Behavior and Lipids (Table 3)

Three cross-sectional studies investigated the association between screen-based sedentary behavior and total cholesterol, LDL-C, HDL-C, and TG.^{21,56,85} Null associations were observed in all 3 studies,^{21,56,85} except for a negative association reported between screen-based sedentary behavior and HDL-C by Byun et al,⁵⁶ which remained after adjusting for MVPA.

Ekelund et al⁷⁸ investigated the cross-sectional association between objectively measured sedentary behavior and HDL-C and TG, and in that study null associations were observed. Mitchell et al⁹ investigated the longitudinal association between television viewing and changes in LDL-C, HDL-C, and TG over time, and observed null associations for each lipid.

Sedentary Behavior and Insulin Sensitivity (Table 4)

Two cross-sectional studies observed associations between more screen-based sedentary behavior and fasting insulin and HOMA-IR.^{21,87} Henderson et al⁸⁷ also observed that more screen-based sedentary behavior was associated with Matsuda Index. The positive associations reported by Henderson et al⁸⁷ remained after adjusting for MVPA but became null after adjusting for obesity. The positive associations reported by Hardy et al. remained after adjusting for aerobic fitness, dietary intake, and obesity.²¹

Henderson et al⁸⁷ observed cross-sectional associations between more objectively measured sedentary behavior and higher fasting insulin, HOMA-IR, and lower Matsuda Index. However, only the fasting insulin and HOMA-IR associations remained after adjusting for MVPA in that study; and only the fasting insulin association remained after adjusting for obesity.⁸⁷ Sardinha et al²³ observed a

cross-sectional association between more objectively measured sedentary behavior and an increase in HOMA-IR. That association remained after adjusting for MVPA and obesity.²³ In contrast, Ekelund et al⁷⁸ reported a positive association between objectively measured sedentary behavior and fasting insulin, but that association was attenuated after adjusting for MVPA.

A case-control study by Lobelo et al⁸⁶ investigated if screen-based sedentary behavior was associated with T2DM. No difference in screen-based sedentary behavior was observed between type 2 diabetic cases and controls, and the null association remained after stratifying by obesity status.⁸⁶

Sedentary Behavior and Clustered Metabolic Risk (Table 5)

Three cross-sectional studies investigated the association between screen-based sedentary behavior and metabolic syndrome.^{20,88,89} In all 3 studies more screen-based sedentary behavior was associated with metabolic syndrome.^{20,88,89} Two of those studies adjusted for MVPA and the positive associations remained in both studies with that adjustment,^{20,88} and the association remained in the one study that adjusted for obesity.²⁰ Hsu et al²⁰ investigated the cross-sectional association between objectively measured sedentary behavior and metabolic syndrome. There was no association between objectively measured sedentary behavior and metabolic syndrome in that study.²⁰

Five cross-sectional studies investigated the association between screen-based sedentary behavior and metabolic risk scores.^{43,91-94} Two studies observed that more screen-based sedentary behavior was associated with higher metabolic risk scores.^{91,93} The positive association remained in one study that adjusted for MVPA and dietary intake⁹³; and remained in one study that adjusted for obesity.⁹¹ Rey-Lopez et al⁹⁴ observed that more video game playing was associated with higher metabolic risk scores in boys, and this association remained after adjusting

for MVPA; however, Rey-Lopez et al⁹⁴ reported null associations between television viewing and metabolic risk score in both boys and girls. Chinapaw et al⁹² reported a null association between screen-based sedentary behavior and metabolic risk score.

Three cross-sectional studies investigated the association between objectively measured sedentary behavior and metabolic risk score.^{90,92,93} Martinez-Gomez et al⁹⁰ observed that more objectively measured sedentary behavior was associated with higher metabolic risk scores, but did not adjust for MVPA, dietary intake, sleep duration, or obesity. Null associations were observed between objectively measured sedentary behavior and metabolic risk scores in the remaining two studies.^{92,93} Mitchell et al⁹ investigated the longitudinal association between television viewing and change in metabolic risk score over time, and observed a null association.

Sedentary Behavior and Fitness (Table 6)

Six cross-sectional studies investigated the association between screen-based sedentary behavior and CRF.⁹⁷⁻¹⁰² In all 6 studies, more screen-based sedentary behavior was associated with lower CRF.⁹⁷⁻¹⁰² The associations remained in all 6 studies after adjusting for obesity; 3 of the 6 studies adjusted for MVPA, and in those studies the negative association between screen-based sedentary behavior and lower CRF remained.^{97,99,101} Martinez-Gomez et al¹⁰⁹ observed a cross-sectional association between more objectively measured sedentary behavior and lower CRF, and that association remained after adjusting for obesity. Interestingly, MVPA modified that association, where more objectively measured sedentary behavior was associated with lower CRF when MVPA levels were low.¹⁰⁹

Five longitudinal studies investigated the association between screen-based sedentary behavior and CRF.^{96,98,100,102,103} Two observed no association between sedentary behavior and change in CRF over time.^{98,103} Three observed that more screen-based sedentary behavior

predicted lower CRF over time.^{96,100,102} The association remained in 2 studies that adjusted for obesity,^{96,102} and in the one study that adjusted for MVPA.⁹⁶

Sedentary Behavior and Other Health Outcomes (Table 7)

Null associations were observed between sedentary behavior and adipokines;¹⁰⁴ markers of inflammation;^{21,104} markers of non-alcoholic fatty liver disease;²¹ and arterial stiffness.¹⁰⁶ More sedentary behavior was cross-sectionally associated with arteriolar narrowing of the retinal microvasculature, and that association remained after adjusting for BMI.¹⁰⁵ Xi et al¹⁰⁷ observed a cross-sectional interaction between sedentary behavior and obesity-susceptibility loci. Specifically, more sedentary behavior was associated with increased BMI and the increase was greater among those genetically susceptible to obesity.¹⁰⁷

Discussion

Youth spend the majority of their waking hours in sedentary behavior and this may have health consequences. On reviewing the literature, we found evidence that too much sedentary behavior associated with obesity in youth. We found an indication that too much sedentary behavior associated with insulin sensitivity, and an indication that too much sedentary behavior associated with clustered metabolic risk. There was evidence that sedentary behavior was associated with lower CRF in youth; but there was little-to-no evidence that too much sedentary behavior associated with impaired lipid profiles and increased blood pressure in youth. Reasons to explain the associations observed in the studies reviewed are provided below, and possible future research directions are also discussed.

Sedentary Behavior and Obesity

Cross-sectional and longitudinal studies reported associations between sedentary behavior, especially screen-based sedentary behavior, and measures of

obesity. The longitudinal findings are important as this indicates a temporal sequence, whereby time spent in sedentary could lead to increases in measures of obesity. A positive energy balance is thought to be the primary mechanism underlying the development of obesity, and spending too much time in sedentary behavior may facilitate a positive energy balance through a reduction in energy expenditure. In some studies the association between sedentary behavior and obesity remained after adjusting for MVPA.¹¹ Those findings suggest that substituting sedentary behavior for light-intensity physical activity, to increase energy expenditure, could correct a positive energy balance and reduce the prevalence of obesity. However, in other studies MVPA modified the association between sedentary behavior and obesity,^{35,36,53,63,69} and in two cross-sectional studies that objectively measured sedentary behavior the association with obesity was attenuated after adjusting for MVPA.^{22,76} These findings suggest that youth with high levels of sedentary behavior should be encouraged to meet the physical activity guidelines, and that this could sufficiently increase energy expenditure to help correct a positive energy balance. While reduced energy expenditure during sedentary behavior appears to be plausible explanation for the observed associations with obesity, it is not known if specific sedentary behavior guidelines are needed beyond current physical activity guidelines to help prevent childhood obesity from an energy expenditure standpoint.

Spending too much time in sedentary behavior may also facilitate a positive energy balance through an increase in energy intake. Snacking while watching television and exposure to televised food advertisements are 2 mechanisms thought to encourage increased energy intake with more time spent in sedentary behavior.⁵ Some studies adjusted for dietary intakes when investigating the

¹¹References 9, 10, 14, 15, 17, 19, 30, 40, 42, 43, 45-47, 50, 56, 60, 62, 70, 71, 74, 79.

association between sedentary behavior and obesity; however, in all of those studies the associations remained.[¶] These findings indicate that the association between sedentary behavior and obesity is not fully explained by increased dietary intakes. However, not all studies used the same measure of dietary intake, and more standardized adjusted for dietary intakes should be adopted in future studies that investigate the association between sedentary behavior and obesity.

Short sleep duration and disrupted circadian rhythms have been associated with obesity.^{110,111} It is possible that the association between sedentary behavior and obesity in youth is explained, in part, by a reduction in sleep duration that disrupts circadian rhythms. In support, children often watch television in the evening,¹¹² which potentially increases exposure to light at night and delays the onset of sleep. Few studies included in this review adjusted for sleep duration when investigating the association between sedentary behavior and obesity, and this adjustment should be considered in future studies.

Sedentary Behavior and Metabolic Risk

There was little-to-no evidence that sedentary behavior was associated with increased blood pressure and blood lipids in youth.^{9,21,56,62,78,82-85} Those findings are in contrast with findings among adults, where associations between sedentary behavior and blood pressure and blood lipids have been reported.¹¹³ It is possible that exposure to high levels of sedentary behavior in youth is of too short a duration to be associated with blood pressure and blood lipids; and long-term exposure to sedentary behavior from childhood into adulthood may be necessary to impair these metabolic risk factors.^{114,115} It is also possible that sedentary behavior first associates with obesity, and then with hypertension and hyperlipidemia later in adulthood.

[¶]References 9, 17, 18, 30, 42, 45, 47, 60, 70, 74, 79.

There was some cross-sectional evidence that too much sedentary behavior was associated with insulin sensitivity^{21,23,78,87} and clustered metabolic risk in youth.^{88-91,93} However, there is a lack of longitudinal studies that have investigated the association between sedentary behavior and insulin sensitivity and clustered metabolic risk, and this is needed to establish temporal precedence. Nonetheless, in some studies the cross-sectional associations between sedentary behavior and those metabolic risk factors remained after adjusting for MVPA.^{21,23,87,88,93} This indicates that substituting sedentary behavior for light intensity physical activity could improve insulin sensitivity and clustered metabolic risk. Also, in some studies the reported associations between sedentary behavior and insulin sensitivity remained after adjusting for obesity.^{21,23} This indicates that reducing sedentary behavior could improve insulin sensitivity, independent of changes in fat mass. Few studies adjusted for dietary intake when assessing the association between sedentary behavior and insulin sensitivity and clustered metabolic risk,^{21, 93} so it is not known if poor diet composition with more sedentary behavior explains the association between sedentary behavior and those metabolic risk factors. Also, only one study adjusted for sleep duration,⁹ so it is not known if short sleep coinciding with more sedentary behavior explains the association between sedentary behavior and those metabolic risk factors.

Sedentary Behavior and Fitness

Cross-sectional and longitudinal studies reported associations between more sedentary behavior and lower CRF.^{97-102,109} Importantly, there is evidence that the association between sedentary behavior and lower CRF is independent of MVPA.^{96,97,99,101} These findings indicate that substituting sedentary behavior for light intensity physical activity could increase CRF levels. However, one study observed that MVPA modified the association between sedentary behavior and CRF, and this finding suggests that

those with high levels of sedentary behavior should be encouraged to meet the physical activity guidelines to improve their CRF.¹⁰⁹ More research is needed to determine if specific sedentary behavior guidelines are needed beyond current physical activity guidelines to help improve CRF levels in youth.

Interestingly, the associations between sedentary behavior and lower CRF remained after adjusting for BMI.^{96-99,101,109} This means that reducing sedentary behavior could increase CRF levels, even if there is no change in BMI. This is important in terms of the fit-fat hypothesis, whereby maintaining moderate-to-high levels of CRF can improve health outcomes, even among those who are obese.¹¹⁶

Future Research

Studies to date have typically assumed that all sedentary behaviors are equal; especially those that have used accelerometry to objectively measure sedentary behavior. However, certain sedentary behaviors may be more harmful to health than others. For example, Gopinath et al⁸² and Sisson et al⁵⁵ both demonstrated that reading was not associated with the health outcome under investigation (blood pressure and obesity, respectively), whereas television viewing was associated with the health outcome under study (blood pressure and obesity, respectively). These findings suggest that not all sedentary behaviors are equal in terms of health effects. Although clusters of sedentary behavior have been described among youth,¹¹⁷ it is not known if certain sedentary behavior patterns are more, or less, likely to be associated with health outcomes in youth. Also, as children age they tend to spend more time in prolonged periods of sedentary behavior,^{6, 7} and it has been shown in adults that more breaks in sedentary behavior are associated with improved metabolic risk profiles, independent of total sedentary behavior;¹¹³ but only one study has investigated the association between breaks and metabolic risk in children and adolescents.⁹³ Furthermore, the timing of sedentary behavior may be

important. Descriptive data among youth show that most television viewing occurs in the evening prior to going to bed,¹¹² and having a television in the bedroom has been associated with obesity, independent of total television viewing.^{47,79} It would be worth investigating the timing of sedentary behavior as evening sedentary behavior may have a role in short sleep and disrupted circadian rhythms.

To accommodate time spent in sedentary behavior, it is likely that less time is spent in light intensity physical activity.^{6,7} If a reduction in energy expenditure with more time spent in sedentary behavior explains, in part, the associations with obesity and lower aerobic fitness in youth, and perhaps impaired metabolic profiles, then substituting sedentary behavior for light intensity physical activity would be expected to improve health outcomes in youth. However, there are few studies that have investigated the health effects of light intensity physical activity. For example, Steele et al. found no association between light intensity physical activity and obesity in youth; and the association between sedentary behavior and obesity in that study became null after adjusting for MVPA.⁷⁶ These findings indicate that energy expended through higher intensity physical activity is more important for preventing obesity. However, there is some evidence in adults that light intensity physical activity can improve health outcomes,^{113,118} and more research in this area is needed, especially among youth.

Xi et al¹⁰⁷ found that screen-based sedentary behavior was associated with increased BMI, and that the association was strongest for those who were genetically susceptible to obesity. This finding provides evidence of a gene-environment interaction, and a similar finding has been reported in a sample of adults.¹¹⁹ This is an area of research that could be explored further. We have studied the BMI distribution in several studies and a common pattern found was that sedentary behavior was associated with increases in BMI, and the increases

were greater at the upper tail of the BMI distribution;^{10,74} and similar associations were observed by Beyerlein et al.⁷⁵ This may provide indirect evidence of a gene-environment interaction, as those at the upper tail of the BMI distribution are more likely to be genetically susceptible to obesity.¹²⁰ In addition to obesity, genes contribute to fitness levels and metabolic risk profiles.^{121,122} and future studies could also determine if gene-environment interactions exist for associations between sedentary behavior and those health outcomes.


Conclusion

Spending too much time in sedentary behavior, especially screen-based sedentary behavior, was associated with obesity and lower aerobic fitness in youth, and these associations were observed in both cross-sectional and longitudinal studies. More time spent in sedentary behavior was cross-sectionally associated with insulin sensitivity and clustered metabolic risk in youth; although, there are no longitudinal studies that support those cross-sectional findings. There was little-to-no evidence that sedentary behavior was associated with increased blood pressure and blood lipids in youth.

Acknowledgments

The author would like to thank Lorraine Dean and Kathleen Sturgeon for commenting on the content of an early draft of the article.

Funding

The author is supported by Award Number F32CA162847 from the National Cancer Institute. The content is solely the responsibility of the author and does not necessarily represent the official views of the National Cancer Institute or the National Institutes of Health. 

References

- Matthews CE, Chen KY, Freedson PS, et al. Amount of time spent in sedentary behaviors in the United States, 2003-2004. *Am J Epidemiol*. 2008;167:875-881.
- Komlos J, Breitfelder A, Sunder M. The transition to post-industrial BMI values among US children. *Am J Hum Biol*. 2009;21:151-160.
- Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. *Exerc Sport Sci Rev*. 2010;38:105-113.
- Pate RR, O'Neill JR, Lobelo F. The evolving definition of "sedentary". *Exerc Sport Sci Rev*. 2008;36:173-178.
- Sisson SB, Shay CM, Broyles ST, Leyva M. Television-viewing time and dietary quality among U.S. children and adults. *Am J Prev Med*. 2012;43:196-200.
- Mitchell JA, Pate RR, Dowda M, et al. A prospective study of sedentary behavior in a large cohort of youth. *Med Sci Sports Exerc*. 2012;44:1081-1087.
- Kwon S, Burns TL, Levy SM, Janz KF. Breaks in sedentary time during childhood and adolescence: Iowa bone development study. *Med Sci Sports Exerc*. 2012;44:1075-1080.
- Ruiz JR, Ortega FB, Martínez-Gómez D, et al. Objectively measured physical activity and sedentary time in European adolescents: the HELENA study. *Am J Epidemiol*. 2011;174:173-184.
- Mitchell JA, Pate RR, Liese AD. Changes in cardiovascular disease risk factors from age 9 to 19 and the influence of television viewing. *Obesity (Silver Spring)*. 2013;21:386-393.
- Mitchell JA, Rodriguez D, Schmitz KH, Audrain-McGovern J. Greater screen time is associated with adolescent obesity: a longitudinal study of the BMI distribution from ages 14 to 18. *Obesity (Silver Spring)*. 2013;21:572-575.
- Chinapaw MJ, Proper KI, Brug J, van Mechelen W, Singh AS. Relationship between young peoples' sedentary behaviour and biomedical health indicators: a systematic review of prospective studies. *Obes Rev*. 2011;12:e621-e632.
- Tremblay MS, LeBlanc AG, Kho ME, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *Int J Behav Nutr Phys Act*. 2011;8:98.
- Atkin AJ, Gorely T, Clemes SA, et al. Methods of measurement in epidemiology: sedentary behaviour. *Int J Epidemiol*. 2012;41:1460-1471.
- Wells JC, Hallal PC, Reichert FF, Menezes AM, Araujo CL, Victora CG. Sleep patterns and television viewing in relation to obesity and blood pressure: evidence from an adolescent Brazilian birth cohort. *Int J Obes*. 2008;32:1042-1049.
- Thibault H, Conrand B, Saubusse E, Baine M, Maurice-Tison S. Risk factors for overweight and obesity in French adolescents: physical activity, sedentary behavior and parental characteristics. *Nutrition*. 2010;26:192-200.
- Anderson SE, Economos CD, Must A. Active play and screen time in US children aged 4 to 11 years in relation to sociodemographic and weight status characteristics: a nationally representative cross-sectional analysis. *BMC Public Health*. 2008;8:366.
- Mushtaq MU, Gull S, Mushtaq K, Shahid U, Shad MA, Akram J. Dietary behaviors, physical activity and sedentary lifestyle associated with overweight and obesity, and their socio-demographic correlates, among Pakistani primary school children. *Int J Behav Nutr Phys Act*. 2011;8:130.
- Lazarou C, Soteriades ES. Children's physical activity, TV watching and obesity in Cyprus: the CYKIDS study. *Eur J Public Health*. 2010;20:70-77.
- Vicente-Rodriguez G, Rey-Lopez JP, Martin-Matillas M, et al. Television watching, videogames, and excess of body fat in Spanish adolescents: the AVENA study. *Nutrition*. 2008;24:654-662.
- Hsu YW, Belcher BR, Ventura EE, et al. Physical activity, sedentary behavior, and the metabolic syndrome in minority youth. *Med Sci Sports Exerc*. 2011;43:2307-2313.
- Hardy LL, Denney-Wilson E, Thrift AP, Okely AD, Baur LA. Screen time and metabolic risk factors among adolescents. *Arch Pediatr Adolesc Med*. 2010;164:643-649.
- Mitchell JA, Mattocks C, Ness AR, et al. Sedentary behavior and obesity in a large cohort of children. *Obesity (Silver Spring)*. 2009;17:1596-1602.
- Sardinha LB, Andersen LB, Anderssen SA, et al. Objectively measured time spent sedentary is associated with insulin resistance independent of overall and central body fat in 9- to 10-year-old Portuguese children. *Diabetes Care*. 2008;31:569-575.
- Basterfield L, Pearce MS, Adamson AJ, et al. Physical activity, sedentary behavior, and adiposity in English children. *Am J Prev Med*. 2012;42:445-451.
- Gaya AR, Alves A, Aires L, Martins CL, Ribeiro JC, Mota J. Association between time spent in sedentary, moderate to vigorous physical activity, body mass index, cardiorespiratory fitness and blood pressure. *Ann Hum Biol*. 2009;36:379-387.

26. Atkin AJ, Ekelund U, Møller NC, et al. Sedentary time in children: influence of accelerometer processing on health relations. *Med Sci Sports Exerc.* 2013;45:1097-1104.
27. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of obesity and trends in body mass index among US children and adolescents, 1999-2010. *JAMA.* 2012;307:483-490.
28. Kuczmarski RJ, Ogden CL, Guo SS, et al. 2000 CDC growth charts for the United States: methods and development. *Vital Health Stat* 11. 2002;(246):1-190.
29. Russ SA, Larson K, Franke TM, Halfon N. Associations between media use and health in US children. *Acad Pediatr.* 2009;9:300-306.
30. Peart T, Velasco Mondragon HE, Rohm-Young D, Bronner Y, Hossain MB. Weight status in US youth: the role of activity, diet, and sedentary behaviors. *Am J Health Behav.* 2011;35:756-764.
31. Perez A, Hoelscher DM, Springer AE, et al. Physical activity, watching television, and the risk of obesity in students, Texas, 2004-2005. *Prev Chronic Dis.* 2011;8:A61.
32. Danner FW. A national longitudinal study of the association between hours of TV viewing and the trajectory of BMI growth among US children. *J Pediatr Psychol.* 2008;33:1100-1107.
33. Treuth MS, Baggett CD, Pratt CA, et al. A longitudinal study of sedentary behavior and overweight in adolescent girls. *Obesity (Silver Spring).* 2009;17:1003-1008.
34. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ.* 2000;320:1240-1243.
35. Eisenmann JC, Bartee RT, Smith DT, Welk GJ, Fu Q. Combined influence of physical activity and television viewing on the risk of overweight in US youth. *Int J Obes.* 2008;32:613-618.
36. Laurson K, Eisenmann JC, Moore S. Lack of association between television viewing, soft drinks, physical activity and body mass index in children. *Acta Paediatr.* 2008;97:795-800.
37. Wells JC, Fewtrell MS. Measuring body composition. *Arch Dis Child.* 2006;91:612-617.
38. Hume C, Singh A, Brug J, Mechelen W, Chinapaw M. Dose-response associations between screen time and overweight among youth. *Int J Pediatr Obes.* 2009;4:61-64.
39. Wen LM, Merom D, Rissel C, Simpson JM. Weight status, modes of travel to school and screen time: a cross-sectional survey of children aged 10-13 years in Sydney. *Health Promot J Austr.* 2010;21:57-63.
40. Tudor-Locke C, Craig CL, Cameron C, Griffiths JM. Canadian children's and youth's pedometer-determined steps/day, parent-reported TV watching time, and overweight/obesity: the CANPLAY Surveillance Study. *Int J Behav Nutr Phys Act.* 2011;8:66.
41. Al-Hazzaa HM, Abahussain NA, Al-Sobayel HI, Qahwaji DM, Musaiger AO. Lifestyle factors associated with overweight and obesity among Saudi adolescents. *BMC Public Health.* 2012;12:354.
42. Morley BC, Scully ML, Niven PH, et al. What factors are associated with excess body weight in Australian secondary school students? *Med J Austr.* 2012;196:189-192.
43. Rey-Lopez JP, Ruiz JR, Vicente-Rodriguez G, et al. Physical activity does not attenuate the obesity risk of TV viewing in youth. *Pediatr Obes.* 2012;7:240-250.
44. Taylor AW, Winefield H, Kettler L, Roberts R, Gill TK. A population study of 5 to 15 year olds: full time maternal employment not associated with high BMI. The importance of screen-based activity, reading for pleasure and sleep duration in children's BMI. *Mater Child Health J.* 2012;16:587-599.
45. Wang N, Xu F, Zheng LQ, et al. Effects of television viewing on body fatness among Chinese children and adolescents. *Chin Med J.* 2012;125:1500-1503.
46. Morales-Ruan Mdel C, Hernandez-Prado B, Gomez-Acosta LM, Shamah-Levy T, Cuevas-Nasu L. Obesity, overweight, screen time and physical activity in Mexican adolescents. *Salud Publica Mex.* 2009;51(suppl 4):S613-S620.
47. Lissner L, Lanfer A, Gwozdz W, et al. Television habits in relation to overweight, diet and taste preferences in European children: the IDEFICS study. *Eur J Epidemiol.* 2012;27:705-715.
48. Moraes L, Lissner L, Yngve A, Poortvliet E, Al-Ansari U, Sjoberg A. Multi-level influences on childhood obesity in Sweden: societal factors, parental determinants and child's lifestyle. *Int J Obes.* 2012;36:969-976.
49. Allender S, Kremer P, de Silva-Sanigorski A, et al. Associations between activity-related behaviours and standardized BMI among Australian adolescents. *J Sci Med Sport.* 2011;14:512-521.
50. Xu F, Li J, Ware RS, Owen N. Associations of television viewing time with excess body weight among urban and rural high-school students in regional mainland China. *Public Health Nutr.* 2008;11:891-896.
51. Fulton JE, Wang X, Yore MM, Carlson SA, Galuska DA, Caspersen CJ. Television viewing, computer use, and BMI among U.S. children and adolescents. *J Phys Act Health.* 2009;6(suppl 1):S28-S35.
52. Steffen LM, Dai S, Fulton JE, Labarthe DR. Overweight in children and adolescents associated with TV viewing and parental weight: Project HeartBeat! *Am J Prev Med.* 2009;37(1 suppl):S50-S55.
53. Wong SL, Leatherdale ST. Association between sedentary behavior, physical activity, and obesity: inactivity among active kids. *Prev Chronic Dis.* 2009;6:A26.
54. Rivera IR, Silva MA, Silva RD, Oliveira BA, Carvalho AC. Physical inactivity, TV-watching hours and body composition in children and adolescents. *Arq Bras Cardiol.* 2010;95:159-165.
55. Sisson SB, Broyles ST, Baker BL, Katzmarzyk PT. Television, reading, and computer time: correlates of school-day leisure-time sedentary behavior and relationship with overweight in children in the U.S. *J Phys Act Health.* 2011;8(suppl 2):S188-S197.
56. Byun W, Dowda M, Pate RR. Associations between screen-based sedentary behavior and cardiovascular disease risk factors in Korean youth. *J Kor Med Sci.* 2012;27:388-394.
57. Tovar A, Chui K, Hyatt RR, et al. Healthy-lifestyle behaviors associated with overweight and obesity in US rural children. *BMC Pediatr.* 2012;12:102.
58. Sisson SB, Broyles ST, Baker BL, Katzmarzyk PT. Screen time, physical activity, and overweight in U.S. youth: national survey of children's health 2003. *J Adolesc Health.* 2010;47:309-311.
59. Aucote HM, Cooper A. Relationships between body fatness, small-screen sedentary activity and regionality among schoolchildren in Victoria, Australia. *Aust J Rural Health.* 2009;17:141-146.
60. Lajous M, Chavarro J, Peterson KE, et al. Screen time and adiposity in adolescents in Mexico. *Public Health Nutr.* 2009;12:1938-1945.
61. Nogueira JA, Macedo da, Costa TH. Gender differences in physical activity, sedentary behavior, and their relation to body composition in active Brazilian adolescents. *J Phys Act Health.* 2009;6:93-98.
62. Ullrich-French SC, Power TG, Daratha KB, Bindler RC, Steele MM. Examination of adolescents' screen time and physical fitness as independent correlates of weight status and blood pressure. *J Sports Sci.* 2010;28:1189-1196.
63. Yen CF, Hsiao RC, Ko CH, et al. The relationships between body mass index

- and television viewing, internet use and cellular phone use: the moderating effects of socio-demographic characteristics and exercise. *Int J Eat Disord.* 2010;43:565-571.
64. Ozmert EN, Ozdemir R, Pektas A, Uckardes Y, Yurdakok K. Effect of activity and television viewing on BMI z-score in early adolescents in Turkey. *World J Pediatr.* 2011;7:37-40.
 65. Colley RC, Wong SL, Garriguet D, Janssen I, Gorber SC, Tremblay MS. Physical activity, sedentary behaviour and sleep in Canadian children: parent-report versus direct measures and relative associations with health risk. *Health Rep.* 2012;23:45-52.
 66. French SA, Mitchell NR, Hannan PJ. Decrease in television viewing predicts lower body mass index at 1-year follow-up in adolescents, but not adults. *J Nutr Educ Behav.* 2012;44:415-422.
 67. Pratt C, Webber LS, Baggett CD, et al. Sedentary activity and body composition of middle school girls: the trial of activity for adolescent girls. *Res Q Exerc Sport.* 2008;79:458-467.
 68. Cecil-Karb R, Grogan-Kaylor A. Childhood body mass index in community context: neighborhood safety, television viewing, and growth trajectories of BMI. *Health Soc Work.* 2009;34:169-177.
 69. Barnett TA, O'Loughlin J, Sabiston CM, et al. Teens and screens: the influence of screen time on adiposity in adolescents. *Am J Epidemiol.* 2010;172:255-262.
 70. Fulton JE, Dai S, Steffen LM, Grunbaum JA, Shah SM, Labarthe DR. Physical activity, energy intake, sedentary behavior, and adiposity in youth. *Am J Prev Med.* 2009;37(1 suppl):S40-S49.
 71. Hands BP, Chivers PT, Parker HE, Beilin L, Kendall G, Larkin D. The associations between physical activity, screen time and weight from 6 to 14 yrs: the Raine Study. *J Sci Med Sport.* 2011;14:397-403.
 72. Altenburg TM, Singh AS, van Mechelen W, Brug J, Chinapaw MJ. Direction of the association between body fatness and self-reported screen time in Dutch adolescents. *Int J Behav Nutr Phys Act.* 2012;9:4.
 73. Fisher A, Hill C, Webber L, Purslow L, Wardle J. MVPA is associated with lower weight gain in 8-10 year old children: a prospective study with 1 year follow-up. *PLoS One.* 2011;6(4):e18576.
 74. Mitchell JA, Pate RR, Beets MW, Nader PR. Time spent in sedentary behavior and changes in childhood BMI: a longitudinal study from ages 9 to 15 years. *Int J Obes.* 2013;37:54-60.
 75. Beyerlein A, Toschke AM, von Kries R. Risk factors for childhood overweight: shift of the mean body mass index and shift of the upper percentiles: results from a cross-sectional study. *Int J Obes.* 2010;34:642-648.
 76. Steele RM, van Sluijs EM, Cassidy A, Griffin SJ, Ekelund U. Targeting sedentary time or moderate- and vigorous-intensity activity: independent relations with adiposity in a population-based sample of 10-y-old British children. *Am J Clin Nutr.* 2009;90:1185-1192.
 77. Chaput JP, Lambert M, Mathieu ME, Tremblay MS, O'Loughlin J, Tremblay A. Physical activity vs. sedentary time: independent associations with adiposity in children. *Pediatr Obes.* 2012;7(3): 251-258.
 78. Ekelund U, Luan J, Sherar LB, et al. Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. *JAMA.* 2012;307:704-712.
 79. Lehto R, Ray C, Lahti-Koski M, Roos E. Health behaviors, waist circumference and waist-to-height ratio in children. *Eur J Clin Nutr.* 2011;65:841-848.
 80. Oliver M, Schluter PJ, Rush E, Schofield GM, Paterson J. Physical activity, sedentariness, and body fatness in a sample of 6-year-old Pacific children. *Int J Pediatr Obes.* 2011;6:e565-e573.
 81. McClain AD, Hsu YW, Belcher BR, Nguyen-Rodriguez S, Weigensberg M, Spruijt-Metz D. Physical inactivity, but not sedentary behavior or energy intake, is associated with higher fat mass in Latina and African American girls. *Ethn Dis.* 2011;21:458-461.
 82. Gopinath B, Baur LA, Hardy LL, et al. Relationship between a range of sedentary behaviours and blood pressure during early adolescence. *J Hum Hypertens.* 2012;26:350-356.
 83. Lazarou C, Panagiotakos DB, Matalas AL. Lifestyle factors are determinants of children's blood pressure levels: the CYKIDS study. *J Hum Hypertens.* 2009;23:456-463.
 84. Martinez-Gomez D, Tucker J, Heelan KA, Welk GJ, Eisenmann JC. Associations between sedentary behavior and blood pressure in young children. *Arch Pediatr Adolesc Med.* 2009;163:724-730.
 85. Goldfield GS, Kenny GP, Hadjiyannakis S, et al. Video game playing is independently associated with blood pressure and lipids in overweight and obese adolescents. *PLoS One.* 2011;6:e26643.
 86. Lobelo F, Liese AD, Liu J, et al. Physical activity and electronic media use in the SEARCH for diabetes in youth case-control study. *Pediatrics.* 2010;125:e1364-e1371.
 87. Henderson M, Gray-Donald K, Mathieu ME, et al. How are physical activity, fitness, and sedentary behavior associated with insulin sensitivity in children? *Diabetes Care.* 2012;35:1272-1278.
 88. Mark AE, Janssen I. Relationship between screen time and metabolic syndrome in adolescents. *J Public Health.* 2008;30: 153-160.
 89. Kang HT, Lee HR, Shim JY, Shin YH, Park BJ, Lee YJ. Association between screen time and metabolic syndrome in children and adolescents in Korea: the 2005 Korean National Health and Nutrition Examination Survey. *Diabetes Res Clin Pract.* 2010;89: 72-78.
 90. Martinez-Gomez D, Eisenmann JC, Gomez-Martinez S, Veses A, Marcos A, Veiga OL. Sedentary behavior, adiposity and cardiovascular risk factors in adolescents. The AFINOS study. *Rev Esp Cardiol.* 2010;63:277-285.
 91. Martinez-Gomez D, Rey-Lopez JP, Chillón P, et al. Excessive TV viewing and cardiovascular disease risk factors in adolescents. The AVENA cross-sectional study. *BMC Public Health.* 2010;10:274.
 92. Chinapaw MJ, Yildirim M, Altenburg TM, et al. Objective and self-rated sedentary time and indicators of metabolic health in Dutch and Hungarian 10-12 year olds: the ENERGY-Project. *PLoS One.* 2012;7(5):e36657.
 93. Carson V, Janssen I. Volume, patterns, and types of sedentary behavior and cardio-metabolic health in children and adolescents: a cross-sectional study. *BMC Public Health.* 2011;11:274.
 94. Rey-López JP, Bel-Serrat S, Santaliestra-Pasias A, et al. Sedentary behaviour and clustered metabolic risk in adolescents: The HELENA study [published online August 17, 2012]. *Nutr Metab Cardiovasc Dis.* doi:10.1016/j.numecd.2012.06.006.
 95. Ortega FB, Artero EG, Ruiz JR, et al. Reliability of health-related physical fitness tests in European adolescents. The HELENA Study. *Int J Obes (Lond).* 2008;32(suppl 5):S49-S57.
 96. Mitchell JA, Pate RR, Blair SN. Screen-based sedentary behavior and cardiorespiratory fitness from age 11 to 13. *Med Sci Sports Exerc.* 2012;44:1302-1309.
 97. Hardy LL, Dobbins TA, Denney-Wilson EA, Okely AD, Booth ML. Sedentariness, small-screen recreation, and fitness in youth. *Am J Prev Med.* 2009;36:120-125.
 98. Aggio D, Ogunleye AA, Voss C, Sandercock GR. Temporal relationships between screen-time and physical activity with cardiorespiratory fitness in English schoolchildren: a 2-year longitudinal study. *Prev Med.* 2012;55:37-39.

99. Sandercock GR, Ogunleye AA. Screen time and passive school travel as independent predictors of cardiorespiratory fitness in youth. *Prev Med*. 2012;54:319-322.
100. Mota J, Ribeiro JC, Carvalho J, Santos MP, Martins J. Television viewing and changes in body mass index and cardiorespiratory fitness over a two-year period in schoolchildren. *Pediatr Exerc Sci*. 2010;22:245-253.
101. Aires L, Pratt M, Lobelo F, Santos RM, Santos MP, Mota J. Associations of cardiorespiratory fitness in children and adolescents with physical activity, active commuting to school, and screen time. *J Phys Act Health*. 2011;8(suppl 2):S198-S205.
102. Lobelo F, Dowda M, Pfeiffer KA, Pate RR. Electronic media exposure and its association with activity-related outcomes in female adolescents: cross-sectional and longitudinal analyses. *J Phys Act Health*. 2009;6:137-143.
103. Aires L, Andersen LB, Mendonca D, Martins C, Silva G, Mota J. A 3-year longitudinal analysis of changes in fitness, physical activity, fatness and screen time. *Acta Paediatr*. 2010;99:140-144.
104. Martinez-Gomez D, Eisenmann JC, Healy GN, et al. Sedentary behaviors and emerging cardiometabolic biomarkers in adolescents. *J Pediatr*. 2012;160:104.e2-110.e2.
105. Gopinath B, Baur LA, Wang JJ, et al. Influence of physical activity and screen time on the retinal microvasculature in young children. *Arterioscler Thromb Vasc Biol*. 2011;31:1233-1239.
106. Nettlefold L, McKay HA, Naylor PJ, Bredin SS, Warburton DE. The relationship between objectively measured physical activity, sedentary time, and vascular health in children. *Am J Hypertens*. 2012;25:914-919.
107. Xi B, Wang C, Wu L, et al. Influence of physical inactivity on associations between single nucleotide polymorphisms and genetic predisposition to childhood obesity. *Am J Epidemiol*. 2011;173:1256-1262.
108. Epstein LH, Roemmich JN, Robinson JL, et al. A randomized trial of the effects of reducing television viewing and computer use on body mass index in young children. *Arch Pediatr Adolesc Med*. 2008;162:239-245.
109. Martinez-Gomez D, Ortega FB, Ruiz JR, et al. Excessive sedentary time and low cardiorespiratory fitness in European adolescents: the HELENA study. *Arch Dis Child*. 2011;96:240-246.
110. Seegers V, Petit D, Falissard B, et al. Short sleep duration and body mass index: a prospective longitudinal study in preadolescence. *Am J Epidemiol*. 2011;173:621-629.
111. Bass J, Takahashi JS. Circadian integration of metabolism and energetics. *Science*. 2010;330:1349-1354.
112. Biddle SJ, Marshall SJ, Gorely T, Cameron N. Temporal and environmental patterns of sedentary and active behaviors during adolescents' leisure time. *Int J Behav Med*. 2009;16:278-286.
113. Healy GN, Dunstan DW, Salmon J, et al. Breaks in sedentary time: beneficial associations with metabolic risk. *Diabetes Care*. 2008;31:661-666.
114. Hancox RJ, Milne BJ, Poulton R. Association between child and adolescent television viewing and adult health: a longitudinal birth cohort study. *Lancet*. 2004;364:257-262.
115. Parsons TJ, Manor O, Power C. Television viewing and obesity: a prospective study in the 1958 British birth cohort. *Eur J Clin Nutr*. 2008;62:1355-1363.
116. McAuley PA, Artero EG, Sui X, et al. The obesity paradox, cardiorespiratory fitness, and coronary heart disease. *Mayo Clin Proc*. 2012;87:443-451.
117. Gorely T, Marshall SJ, Biddle SJ, Cameron N. Patterns of sedentary behaviour and physical activity among adolescents in the United Kingdom: Project STIL. *J Behav Med*. 2007;30:521-531.
118. Buman MP, Hekler EB, Haskell WL, et al. Objective light-intensity physical activity associations with rated health in older adults. *Am J Epidemiol*. 2010;172:1155-1165.
119. Qi Q, Li Y, Chomistek AK, et al. Television watching, leisure time physical activity, and the genetic predisposition in relation to body mass index in women and men. *Circulation*. 2012;126:1821-1827.
120. Speliotes EK, Willer CJ, Berndt SI, et al. Association analyses of 249,796 individuals reveal 18 new loci associated with body mass index. *Nat Genet*. 2010;42:937-948.
121. Roth SM, Rankinen T, Hagberg JM, et al. Advances in exercise, fitness, and performance genomics in 2011. *Med Sci Sports Exerc*. 2012;44:809-817.
122. Manning AK, Hivert MF, Scott RA, et al. A genome-wide approach accounting for body mass index identifies genetic variants influencing fasting glycemic traits and insulin resistance. *Nat Genet*. 2012;44:659-669.